

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
1 April 1999

3. REPORT TYPE AND DATES COVERED
Final: 1 Feb 1997 - 31 Dec 1998

4. TITLE AND SUBTITLE

Analysis of Subsurface Velocity Data from the Arctic Ocean

5. FUNDING NUMBERS

(G)rant
N00014-97-1-0135

6. AUTHOR(S)

Albert J. Plueddemann

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Woods Hole Oceanographic Institution
Mail Stop #21
Woods Hole, Massachusetts 02543

8. PERFORMING ORGANIZATION
REPORT NUMBER

13013500

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217-5660

Attn: ONR Code 322HL
Dennis Conlon

10. SPONSORING/MONITORING
AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Attn: Boston Regional Office

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for Public Release, Distribution is Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Velocity data in the upper 250-m observed by an Acoustic Doppler Current Profiler suspended below a buoy frozen into the Arctic pack ice were used for two investigations. First, the role of low-frequency waves over the Yermak Plateau in the generation and propagation of near-inertial internal waves was examined. The temporal variations of wavenumber-frequency spectra over the Yermak Plateau showed that intense, upward propagating near-inertial wave groups occurred when high-mode, low-frequency waves were present. The time and depth variation of near-inertial wave parameters were related to changes in background conditions caused by the low-frequency waves. Second, the regional and temporal variability of internal waves, tides and eddies in the Beaufort Sea were documented. Variability in the eddy band was high in the northwest Beaufort Sea and along the southwest slope of the Canada Basin, dropping abruptly when the buoy left the basin. The principal characteristic of the inertial-band was seasonal variability, with amplitudes largest in late summer and smallest in late winter. Amplitudes in the diurnal band were generally weak, with the exception of the K1 tide over shallow topography.

14. SUBJECT TERMS

Arctic; eddies; internal waves; tides

15. NUMBER OF PAGES

5

16. PRICE CODE

17. SECURITY CLASSIFICATION
OF REPORT
Unclassified

18. SECURITY CLASSIFICATION
OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION
OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL

Analysis of Subsurface Velocity Data from the Arctic Ocean

FINAL REPORT

Albert J. Plueddemann

Department of Physical Oceanography
Woods Hole Oceanographic Institution, Woods Hole, MA 02543

ONR Grant N00014-97-1-0135

01 Feb 1997 - 31 Dec 1998

Objectives

The long-range goal is to document characteristics of the subsurface velocity field in the Arctic Ocean and investigate the dynamics which determine those characteristics. The research was composed of two parts. The objective of the first part was to investigate the role of low-frequency waves over the Yermak Plateau in the generation and propagation of near-inertial internal waves. The objective of the second part was to document the regional and temporal variability of internal waves, tides and eddies in the Beaufort Sea.

Background

The first part of the investigation utilized data from the Arctic Environmental Drifting Buoy (AEDB; Honjo *et al.*, 1990) which was deployed on a multi-year ice floe near 86° N, 22° E in August of 1987. The surface flotation sphere of the AEDB was intentionally frozen into the pack ice and served as the "anchor" for a 125 m instrumented mooring line suspended below. The AEDB was deployed in the Nansen Basin and recovered in the Denmark Strait over eight months later, having drifted over the Yermak Plateau and into the Greenland Sea. Velocities in the upper 250 m were observed by an Acoustic Doppler Current Profiler (ADCP) attached to the mooring line.

The second part of the investigation utilized data from a second-generation Arctic buoy denoted the Ice-Ocean Environmental Buoy (IOEB; Krishfield *et al.*, 1993) which was deployed in the Beaufort Sea in April of 1992. A data processing module was developed to serve as an interface between the ADCP and the telemetry package on the buoy (Plueddemann *et al.*, 1992). The module averaged the ADCP velocity profiles in depth and time and provided the results, along with quality control information, to the telemetry controller on demand. The processing module was successfully used to obtain over 23 months of velocity data via Argos telemetry as the buoy drifted in a broad, anticyclonic arc within the Beaufort Gyre from its starting point about 250 km north of Prudhoe Bay, Alaska.

19990412 058

DMC QUALITY INSPECTED 2

Part 1: Internal Waves over the Yermak Plateau

Previous analyses (Plueddemann, 1992; D'Asaro and Morison, 1992) have shown that the internal wave field over the Yermak Plateau is dominated by upward-propagating, near-inertial internal wave groups. The total energy in the internal wave band is similar to that expected for mid-latitudes (Levine *et al.*, 1985), yet the region is completely ice covered. Diurnal tidal oscillations a factor of 50 more energetic than in the Nansen Basin were also observed over the Plateau (Padman *et al.*, 1992), and it was speculated that the upward propagating wave groups were generated by interaction of strong tidal currents with bottom topography. The M_2 tidal frequency is below local inertial, and would not be expected to generate freely propagating near-inertial waves unless the effective inertial frequency was decreased due to anticyclonic vorticity in the background current field. Another possibility is that the near-inertial waves are generated by harmonics of the strong diurnal tide. In particular, the first harmonic of the K_1 tide is near the resonance frequency for barotropic shelf waves on the eastern slope of the plateau (Padman *et al.*, 1992) and just above the local inertial frequency.

The temporal variations of wavenumber-frequency spectra from the AEDB over the Yermak Plateau showed that the most intense near-inertial wave groups occurred when high-mode, low-frequency waves were present. The low-frequency waves consisted of both upward and downward propagating components which often created an interference pattern with large velocities and large vertical shears. The time and depth variation of near-inertial wave parameters appeared to be related to changes in background conditions caused by the low-frequency waves (Konyaev *et al.*, submitted). In particular, the most intense near-inertial waves occurred when the vertical shear vector of the low-frequency current was nearly opposite to the near-inertial wavenumber vector (Figure 1).

Part 2: Internal waves, tides and eddies in the Beaufort Sea

Time-evolving spectral analysis was used to examine velocity variability in two frequency bands: an eddy band (2–5 day periods) and an inertial band (11.6–12.8 hour periods). Diurnal tidal constituents O_1 and K_1 were extracted by complex demodulation. The eddy band and the semidiurnal band dominated the horizontal kinetic energy (Figure 2).

Velocity variability in the eddy band was high in the northwest Beaufort Sea and along the southwest slope of the Canada Basin, dropping abruptly when the buoy left the basin. Twenty periods of probable eddy variability, distinguished by sustained subsurface velocity maxima of 10 cm s^{-1} or greater, were observed. The maximum velocities were generally found between 100 and 150 m. Of the 10 most clearly identifiable eddies, all but one showed anticyclonic rotation. It has been known for some time that eddies populate this region of the Arctic Ocean (Manley and Hunkins, 1985), but the IOEB observations are of interest in that they extend the region of observed eddies significantly further south and west in the Canada Basin.

The principal characteristic of the inertial-band amplitude was seasonal variability, with amplitudes largest in late summer and smallest in late winter. This was presumably due to seasonal changes in the pack ice. Fragmented summer ice supports very little internal stress. As a result, surface winds generate inertial currents and downward propagating near-inertial waves analogous to those in the open ocean. In winter much of the wind stress is converted to internal stress in the tightly packed ice and inertial currents are weak or absent.

Amplitudes in the diurnal band were generally weak, with the exception of the K_1 tide over shallow topography. The expectation of an enhanced, clockwise-rotating K_1 tide over the shallow, northward projection of the Chukchi Shelf was borne out in the observations. However, enhancement predicted over the northwest Chukchi Plateau was not observed.

References (* indicates publication supported by ONR N00014-90-J-1359)

- D'Asaro, E.A., and J.H. Morison, 1992. Internal waves and mixing in the Arctic Ocean. *Deep-Sea Res.*, **39**, Suppl.2, S459-S484.
- Honjo, S., R. Krishfield and A. Plueddemann, 1990. The Arctic Environmental Drifting Buoy (AEDB): Report of field operations and results. *Tech. Rept. WHOI-90-02*, Woods Hole Oceanographic Institution Woods Hole, MA, 128 pp.
- *Konyaev, K.V., A.J. Plueddemann and K.D. Sabinin, Semi-diurnal internal waves over the Yermak Plateau and their connection with low-frequency currents. *Deep-Sea Res.*, submitted.
- Krishfield, R., K. Doherty and S. Honjo, 1993. Ice-Ocean Environmental Buoys (IOEB): Technology and Development in 1991-1992. *Woods Hole Oceanogr. Inst. Tech. Rep.*, WHOI-93-45, 138 pp.
- Levine, M.D., C.A. Paulson, and J.H. Morison, 1985. Internal waves in the Arctic Ocean: Comparison with lower-latitude observations. *J. Phys. Oceanogr.*, **15**, 800-809.
- Manley, T. O. and K. Hunkins, 1985. Mesoscale eddies of the Arctic Ocean. *J. Geophys. Res.*, **90**, 4911-4930.
- Padman, L., A.J. Plueddemann, R.D. Muench and R. Pinkel, 1992. Diurnal tides near the Yermak Plateau. *J. Geophys. Res.*, **97**(C8), 12,639-12,652.
- Plueddemann, A.J., 1992. Internal wave observations from the Arctic Environmental Drifting Buoy. *J. Geophys. Res.*, **97**(C8), 12,619-12,638.
- Plueddemann, A.J., A.L. Oien, R.C. Singer and S.P. Smith, 1992. A data processing module for acoustic Doppler current meters. *Woods Hole Oceanogr. Inst. Tech. Rep.*, WHOI-92-05, 64 pp.
- *Plueddemann, A.J., R. Krishfield, T. Takizawa, K. Hatakeyama and S. Honjo, 1998. Upper ocean velocities in the Beaufort Gyre. *Geophys. Res. Lett.*, **25**(2), 183-186.

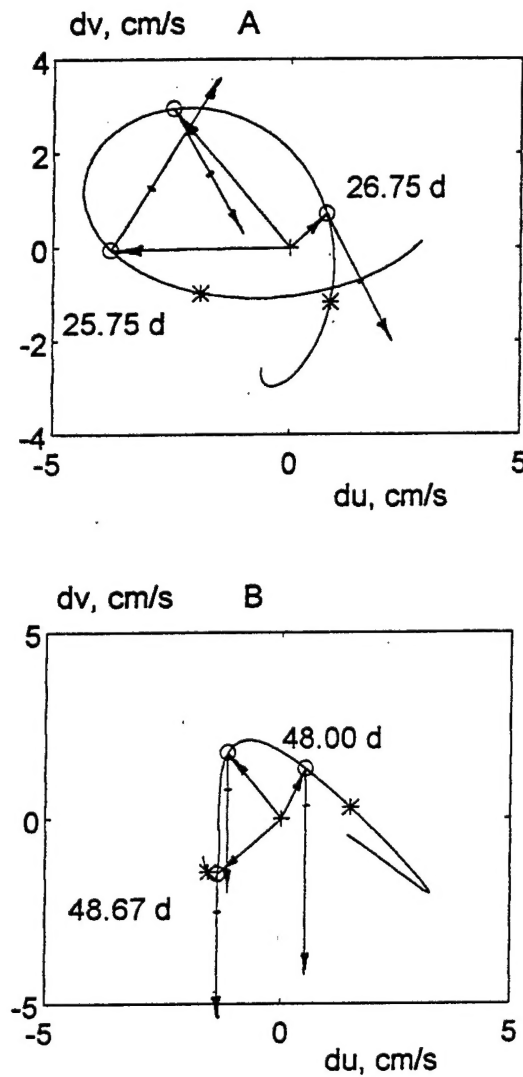


Figure 1: Hodographs of low-frequency vertical shear during the occurrence of strong near-inertial wave groups denoted Group A (upper panel) and Group B (lower panel). Arrows representing the shear vector are drawn from the origin (cross) for three times near the start, middle and end of the analysis period. Horizontal wavenumber vectors for the semidiurnal waves at these three times are drawn from the corresponding points on the hodographs. The times when near-inertial waves are most intense (solid circles) correspond to the times when the low-frequency shear vector is most nearly opposite to the near-inertial wavenumber vector.

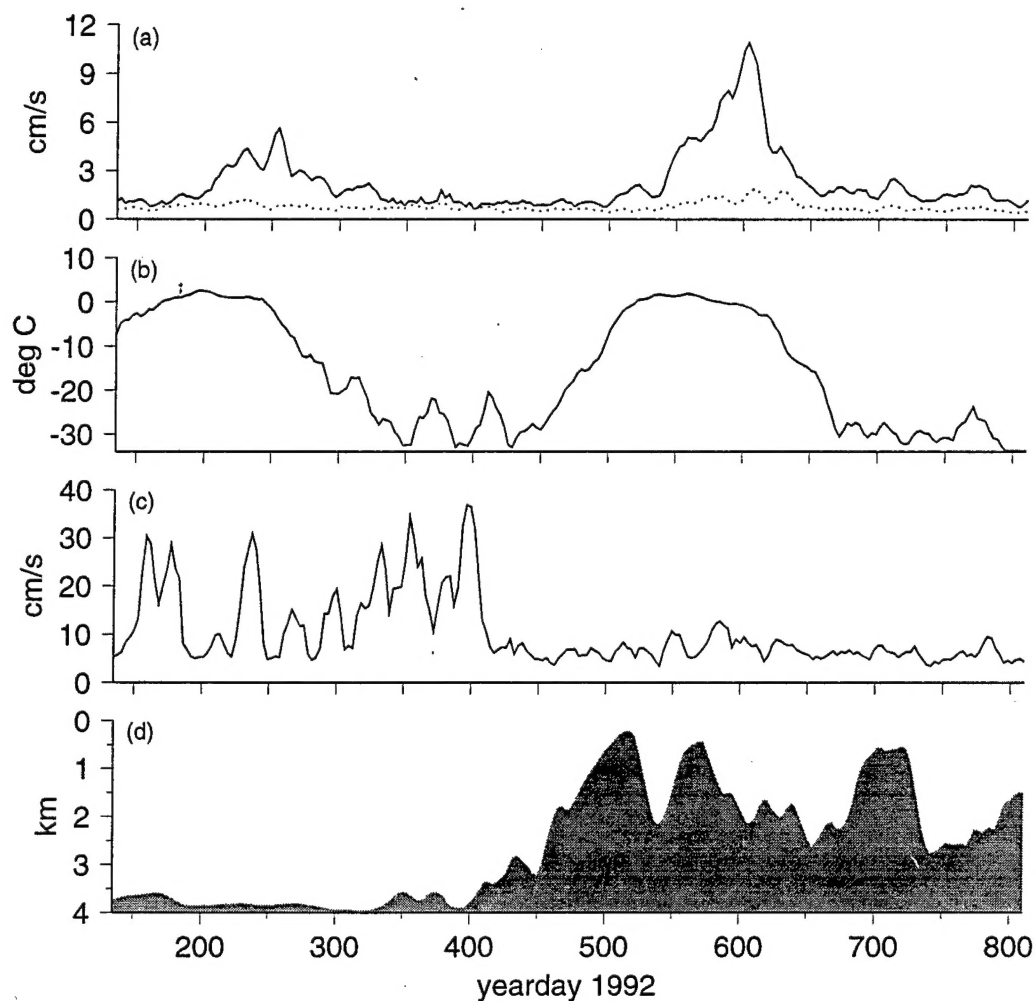


Figure 2: Inertial-band and eddy-band amplitudes. (a) Inertial-band amplitudes separated into clockwise (solid) and counter-clockwise (dotted) components and averaged from the surface to the second ADCP bin (106 m). (b) Air temperature observed at the IOEB indicating seasonal evolution (the sensor could not register temperatures less than -35°C). (c) Eddy-band amplitudes averaged over ADCP depth bins 2–3 (106–154 m). (d) Water depth along the drift track.